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Workload Analysis of the Crew of the Abrams V2 SEP: Phase I Baseline IMPRINT Model

by Diane Kuhl Mitchell

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Diane Kuhl Mitchell
Human Research and Engineering Directorate, ARL

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1. Introduction

The Abrams tank (M1A1) has been in the U. S. Army inventory of combat platforms since 1978. Over the decades, system engineers have enhanced this platform by adding new technologies that provide the Soldiers operating it with new capabilities. For example, the latest version of the Abrams (M1A2 V2 SEP) includes, as part of the system enhancement package (SEP), the Army's Force XXI command and control system. The next set of enhancements, Army program managers plan to add to the platform are some of the capabilities developed as spin- outs from the Future Combat System (FCS) program or Early–Infantry Brigade Combat Team (I–EBCT) technologies.

When the program managers add new technologies to the Abrams, these technologies have the potential to change the Soldiers' tasks. The tasks Soldiers perform, in turn, determine the Soldiers' workload level and their performance. Too little or too much workload decreases their performance (Wickens, 1991). The design goal for optimum Soldier performance is to have evenly distributed, manageable workload. To meet this design goal, the Abrams program manager and system designers need to evaluate the impacts of new technologies on Soldier tasks, workload and performance.

To evaluate the impacts that in system design changes have on Soldier tasks, workload and performance, the system engineers can compare the Soldiers' workload and performance with the fielded Abrams to their workload and performance with the enhanced system. By completing this comparison, the engineers can identify task combinations that contribute to high workload and decrements in Soldier performance before their final design is completed. Because the design is still conceptual, they can modify it to make it more likely that their design is optimal for the Soldiers' operating the Abrams. To achieve this goal, the Abrams' program manager requested researchers working for the U.S. Army Research Laboratory (ARL) to predict the tasks, workload and performance of Soldiers operating the Abrams V2 SEP with and without new technologies.

2. Objectives

The ARL HRED analysts developed a model to represent the tasks performed by each member of the Abrams V2 SEP crew. They then used this model to predict the mental workload of the crew and its impacts on the performance of the crew of the Abrams V2 SEP. The phase I analysis and its workload predictions will serve as a baseline for a phase II analysis. The phase II analysis will predict the impact of specific additional technologies added to the Abrams on

Soldier workload and performance. The phase II technologies ARL will evaluate have not been determined at this time.

3. Methodology

To accomplish the objective, the ARL analyst used the Improved Performance Research Integration Tool (IMPRINT) (http://www.arl.army.mil/IMPRINT). IMPRINT is a human performance-modeling tool that provides analysts with a graphic user interface (GUI) for representing humans performing tasks. The ARL analyst used the IMPRINT GUI to create the representations of the crew of the Abrams as they performed tasks to accomplish their combat mission. These representations of the Abrams operators are task-network models.

In addition to the GUI, IMPRINT provides analysts with the capability to run the task-network models multiple times and view a dynamic simulation of the humans as they perform their tasks. The ARL analysts used this capability to complete multiple model runs of the Abrams V2 SEP crew performing their tasks. The IMPRINT models ran stochastically, which meant that the Abrams crewmembers in the model performed their tasks in different sequences for each model run. During one model run, for example, the gunner might see and identify a target, while in the next run he might miss seeing the target.

Each of the tasks in the IMPRINT model contained analyst input data input used to predict performance of the Abrams crewmembers. These data include time to complete a task, standard deviations for task completion times, and crewmember assigned to complete the task. To help the analysts determine appropriate task times, IMPRINT contains micromodels. The micromodels contain times derived from experiments for such basic human tasks as speaking, reading, walking, head movement, etc. The analyst used the micromodels to determine the times for the tasks in their models that represented the Abrams crew. The analyst used the mental workload option in IMPRINT to predict the crewmembers' workload.

3.1 IMPRINT Mental Workload and Performance

Wickens' Multiple Resource Theory (MRT) is the basis for the workload prediction capability in IMPRINT (Wickens, 1991). According to MRT, the mental resources humans use to perceive information, process the information, and make a response are limited. For example, it is difficult for an individual to look at two different displays at the same time due to limitations on the human visual capabilities. Therefore, when individuals are required to perform multiple tasks at the same time, they may have performance problems. The performance problems occur because the multiple tasks place demands simultaneously on the individual's mental resources. Because the mental resources are limited, the human adjusts performance to compensate for the concurrent demands. The performance problems are greater if the individual is performing two tasks that require the same resource, e.g., two visual tasks than for tasks requiring two different resources, e. g., vision and hearing. The mental workload predicted by IMPRINT represents the total overall demands the tasks place upon the individual's limited mental resources. The IMPRINT algorithm calculates the multiple task demands. If the demands on the individual's limited resources are high, then this represents high mental workload. High mental workload, in turn, indicates the individual will adjust his or her behavior to compensate for the high demands. This performance compensation is associated with a greater number of errors, increased task time, or both (Wickens, 1991).

To estimate the task demands or the amount of each mental resource an individual uses to complete a task, IMPRINT has workload scales. These scales are 7-point behaviorally anchored rating scales developed by McCracken and Aldrich (1984). Table 1 displays the scales. To build the workload analysis in IMPRINT for this project, the ARL analyst started with the task-network models they had created to represent the crewmembers of the Abrams. Next, they allocated the tasks needed to complete an Abrams mission to the crewmember that would complete the tasks. Next, the analyst determined which of the mental resources, (visual, auditory, cognitive, motor, or speech) the Soldier in the experiment would use for each task. The analyst then read the workload descriptors in the scale for the selected resource(s) and selected the descriptor(s) that matched the workload demanded by each task. To calculate the mental workload for each Soldier, IMPRINT automatically populated the workload algorithm with matching data based on the workload descriptors the analyst selected. Finally, the workload algorithm embedded in IMPRINT aggregated the mental workload and provided the ARL analysts with an overall workload estimate for each crewmember each time a new task began in the mission. For this project, when the overall workload predicted by IMPRINT exceeded 7 for visual, auditory, motor or cognitive resource for all tasks occurring simultaneously the analyst considered the crew member to be in a state of high workload for that resource. The analysts used the number seven as their high workload threshold because seven is the workload threshold recommended by McCracken and Aldrich (1984) when they developed and validated the workload rating scales. Because each of the workload channel scales (with the exception of speech) goes to a maximum of 7, an overall workload rating of 28 is a workload threshold that represents maximum load on multiple channels or extreme overload within one channel. Therefore, 28 is the overall workload number used for this project to indicate overload. Mitchell (2000) provides a thorough description of mental workload theory and the model in IMPRINT.

3.2 IMPRINT Abrams Model Inputs

The ARL analysts modified the Abrams M1A1 model provided in the IMPRINT tool library of models to represent the Abrams M1A2 SEP. They modified the IMPRINT library model by incorporating a list of Abrams V2 SEP interfaces. The existing library model includes no interfaces. In addition, they incorporated workload data into the model. The existing library model contains no workload data. They used micromodels to determine the task times based on the interfaces available to the V2 SEP crew. Table 2 displays the times and workload inputs.

Table 1. IMPRINT workload scales based on McCracken and Aldrich, 1984.

Scale Value	Descriptors
	Visually unaided (naked eye)
3.0	Visually register/detect (detect occurrence of image)
5.0	Visually discriminate (detect visual differences)
3.0	Visually inspect/check (discrete inspection/static condition)
4.0	Visually locate/align (selective orientation)
4.4	Visually track/follow (maintain orientation)
5.0	Visually read (symbol)
6.0	Visually scan/search monitor (continuous/serial inspection)
	Visually aided (night vision goggle)
5.0	Visually register/detect (detect occurrence of image)
5.0	Visually inspect/check (discrete inspection/static condition)
7.0	Visually discriminate (detect visual differences)
5.0	Visually locate/align (selective orientation)
5.4	Visually track/follow (maintain orientation)
7.0	Visually scan/search monitor (continuous/serial inspection)
	Auditory
1.0	Detect/register sound (detect occurrence of sound)
2.0	Orient to sound (general orientation/attention)
4.2	Orient to sound (selective orientation/attention)
4.3	Verify auditory feedback (detect occurrence of anticipated sound)
3.0	Interpret semantic content (speech) simple (1 to 2 words)
6.0	Interpret semantic content (speech) complex (Sentence)
6.6	Discriminate sound characteristics (detect auditory difference)
7.0	Interpret sound patterns (pulse rates, etc.)
	Cognitive
1.0	Automatic (simple association)
1.2	Alternative selection
3.7	Sign/Signal recognition
4.6	Evaluation/judgment (consider single aspect)
5.3	Encoding/decoding, recall
6.8	Evaluation/judgment
7.0	Estimation, calculation, conversion
5.0	Rehearsal
	Speech
2.0	Speech simple (1 to 2 words)
4.0	Complex (sentence)
	Fine Motor
2.2	Discrete actuation (button, toggle, trigger)
2.6	Continuous adjustive (flight control, sensor control)
4.6	Manipulative
5.5	Discrete adjustment (rotary, vertical thumbwheel, lever position)
6.5	Symbolic production (writing)
7.0	Serial discrete manipulation (keyboard entries)
	Gross Motor
1.0	Walking on level terrain
2.0	Walking on uneven terrain
3.0	Jogging on level terrain
3.5	Heavy Lifting
5.0	Jogging on uneven terrain
6.0	Complex climbing

Table 2. Model task times and workload/data.

Function	Task	Time HH:MM:SS.SS	Visual	Auditory	Cognitive	Fine Motor	Gross Motor	Speech
Prepare Communications System for Operation	(TC) Put On CVC	00:00:00.45			1.0	4.6		
Prepare Communications System for Operation	(TC) Connect Cable	00:00:00.37	4.0		1.0	2.2		
Prepare Communications System for Operation	(TC) Set “Work” Switch to INT	00:00:00.78	5.0		1.2	2.2		
Prepare Communications System for Operation	(TC) Set “INTERCOM” Switch to PTT	00:00:00.78			1.2	2.2		
Prepare Communications System for Operation	(TC) Set Volume	00:00:00.73		6.6	4.6	5.5		
Prepare Communications System for Operation	(G) Put On CVC	00:00:00.45			1.0	4.6		
Prepare Communications System for Operation	(G) Connect Cable	00:00:00.37	4.0		1.0	2.2		
Prepare Communications System for Operation	(G) Set “Work” Switch to INT	00:00:00.78	5.0		1.2	2.2		
Prepare Communications System for Operation	(G) Set “INTERCOM” Switch to PTT	00:00:00.78			1.2	2.2		
Prepare Communications System for Operation	(G) Set Volume	00:00:00.73		6.6	4.6	5.5		
Prepare Communications System for Operation	(L) Put On CVC	00:00:00.45			1.0	4.6		
Prepare Communications System for Operation	(L) Connect Cable	00:00:00.37	4.0		1.0	2.2		
Prepare Communications System for Operation	(L) Set “Work” Switch to INT	00:00:00.78	5.0		1.2	2.2		
Prepare Communications System for Operation	(L) Set “INTERCOM” Switch to PTT	00:00:00.78			1.2	2.2		

Table 2. Model task times and workload/data (continued).

Function	Task	Time HH:MM:SS.SS	Visual	Auditory	Cognitive	Fine Motor	Gross Motor	Speech
Prepare Communications System for Operation	(L) Set Volume	00:00:00.73		6.6	4.6	5.5		
Prepare Communications System for Operation	(D) Put On CVC	00:00:00.45			1.0	4.6		
Prepare Communications System for Operation	(D) Connect Cable	00:00:00.37	4.0		1.0	2.2		
Prepare Communications System for Operation	(D) Set “Work” Switch to INT	00:00:00.78	5.0		1.2	2.2		
Prepare Communications System for Operation	(D) Set “INTERCOM” Switch to PTT	00:00:00.78			1.2	2.2		
Prepare Communications System for Operation	(D) Set Volume	00:00:00.73		6.6	4.6	5.5		
Refuel Tank	(D) Refuel Tank	00:11:02.82	6.0		4.6			
Stow Ammunition	(TC) Stow 0.50 Cal Ammo	00:16:48.64	4.0		4.6		3.5	
Stow Ammunition	(G) Stow 7.62 Ammunition	00:17:45.07	4.0		4.6		3.5	
Stow Ammunition	(L) Stow Main Gun Ammo	00:41:36.35	4.0		4.6		3.5	
Stow Ammunition	(D) Stow Main Gun Ammo	00:12:03.83	4.0		4.6		3.5	
Stow Ammunition	(D) Stow 5.56 Ammo	00:10:45.45	4.0		4.6		3.5	
Prepare Stations for Operation	(TC) Prepare Station for Operation	00:00:53.54	5.0		6.8	5.5		
Prepare Stations for Operation	(TC) Install 0.50 cal Machine Gun	00:00:37.19	4.0		6.8		3.5	
Prepare Stations for Operation	(G) Prepare Station for Operation	00:01:46.81	5.0		6.8	5.5		

Table 2. Model task times and workload/data (continued).

Function	Task	Time HH:MM:SS.SS	Visual	Auditory	Cognitive	Fine Motor	Gross Motor	Speech
Prepare Stations for Operation	(G) Install M240 Coax Machine Gun	00:00:22.93	4.0		6.8		3.5	
Prepare Stations for Operation	(L) Prepare Station for Operation	00:02:07.47	5.0		6.8	5.5		
Prepare Stations for Operation	(L) Install M240 Machine Gun	00:00:48.64	4.0		6.8		3.5	
Prepare Stations for Operation	(D) Prepare Station for Operation	00:04:41.90	6.0		6.8	5.5		
Perform Before Operations PMCS	(TC) Perform Before Operations Checks	00:02:05.64	5.0		6.8	7.0		
Perform Before Operations PMCS	(G) Perform Before Operations Checks	00:06:13.73	5.0		6.8	5.5		
Perform Before Operations PMCS	(L) Perform Before Operations Checks	00:04:42.20	5.0		6.8	5.5		
Perform Before Operations PMCS	(D) Perform Before Operations Checks	00:04:12.80	5.0		6.8	5.5		
Perform Prefire Checks	(TC) Perform Pre-fire Checks	00:03:23.34	5.0		6.8	5.5		
Perform Prefire Checks	(G) Perform Pre-fire Checks	00:04:07.63	5.0		6.8	5.5		
Perform Prefire Checks	(L) Perform Pre-fire Checks	00:04:24.38	5.0		6.8	5.5		
Boresight and Zero Weapons	(TC) Boresight 0.50 cal Machine Gun	00:11:23.24	4.4		7.0	4.6		
Boresight and Zero Weapons	(G) Boresight + System Calibrate Main Gun	00:18:52.27	4.4		7.0	5.5		
Boresight and Zero Weapons	(TC) Zero 0.50 cal Machine Gun	00:01:36.45	4.4		7.0	5.5		
Boresight and Zero Weapons	(G) Zero M240 Coax Machine Gun	00:02:35.38	4.4		7.0	5.5		

Table 2. Model task times and workload/data (continued).

Function	Task	Time HH:MM:SS.SS	Visual	Auditory	Cognitive	Fine Motor	Gross Motor	Speech
Move to Start Point	(D) Steer Tank	Varies 12–15 min			4.6	2.6		
Move to Start Point	(D) Power Tank	00:00:00.40	5.1		1.2	2.2		
Move to Start Point	(D) Monitor Instruments	Varies 1–5 s	3.0		6.8			
Move to Start Point	(D) Monitor Forward Terrain	Varies 5–15 min	6.0		6.8			
Move to Start Point	(TC) Assign Sector Searches	00:00:01.45			7.0			2.0
Move to Start Point	(TC) Conduct Surveillance	Varies 12–15 min	6.0		6.8	4.6		
Move to Start Point	(G) Conduct Surveillance	Varies 12–15 min	6.0		6.8	4.6		
Move to Start Point	(L) Conduct Surveillance	Varies 12–15 min	6.0		6.8	4.6		
Move to Check Point	(D) Steer Tank	Varies 12–15 min			4.6	2.6		
Move to Check Point	(D) Power Tank	00:00:00.40	5.1		1.2	2.2		
Move to Check Point	(D) Monitor Instruments	Varies 1–5 s	3.0		6.8			
Move to Check Point	(D) Monitor Forward Terrain	Varies 5–15 min	6.0		6.8			
Move to Check Point	(TC) Assign Sector Searches	00:00:01.45			7.0			2.0
Move to Check Point	(TC) Conduct Surveillance	Varies 12–15 min	6.0		6.8	4.6		
Move to Check Point	(G) Conduct Surveillance	Varies 12–15 min	6.0		6.8	4.6		

Table 2. Model task times and workload/data (continued).

Function	Task	Time HH:MM:SS.SS	Visual	Auditory	Cognitive	Fine Motor	Gross Motor	Speech
Move to Check Point	(L) Conduct Surveillance	Varies 12–15 min	6.0		6.8	4.6		
Move to Release Point	(D) Steer Tank	Varies 12–15 min			4.6	2.6		
Move to Release Point	(D) Power Tank	00:00:00.40	5.1		1.2	2.2		
Move to Release Point	(D) Monitor Instruments	Varies 1–5 s	3.0		6.8			
Move to Release Point	(D) Monitor Forward Terrain	Varies 5–15 min	6.0		6.8			
Move to Release Point	(TC) Assign Sector Searches	00:00:01.45			7.0			2.0
Move to Release Point	(TC) Conduct Surveillance	Varies 12–15 min	6.0		6.8	4.6		
Move to Release Point	(G) Conduct Surveillance	Varies 12–15 min	6.0		6.8	4.6		
Move to Release Point	(L) Conduct Surveillance	Varies 12–15 min	6.0		6.8	4.6		
Move to Line of Departure	(D) Steer Tank	Varies 12–15 min			4.6	2.6		
Move to Line of Departure	(D) Power Tank	00:00:00.40	5.1		1.2	2.2		
Move to Line of Departure	(D) Monitor Instruments	Varies 1–5 s	3.0		6.8			
Move to Line of Departure	(D) Monitor Forward Terrain	Varies 5–15 min	6.0		6.8			
Move to Line of Departure	(TC) Assign Sector Searches	00:00:01.45			7.0			2.0
Move to Line of Departure	(TC) Conduct Surveillance	Varies 12–15 min	6.0		6.8	4.6		

Table 2. Model task times and workload/data (continued).

Function	Task	Time HH:MM:SS.SS	Visual	Auditory	Cognitive	Fine Motor	Gross Motor	Speech
Move to Line of Departure	(G) Conduct Surveillance	Varies 12–15 min	6.0		6.8	4.6		
Move to Line of Departure	(L) Conduct Surveillance	Varies 12–15 min	6.0		6.8	4.6		
Move Beyond LD No firing	(D) Steer Tank	Varies 12–15 min			4.6	2.6		
Move Beyond LD No firing	(D) Power Tank	00:00:00.40	5.1		1.2	2.2		
Move Beyond LD No firing	(D) Monitor Instruments	Varies 1–5 s	3.0		6.8			
Move Beyond LD No firing	(D) Monitor Forward Terrain	Varies 5–15 min	6.0		6.8			
Move Beyond LD No firing	(TC) Assign Sector Searches	00:00:01.45			7.0			2.0
Move Beyond LD No firing	(TC) Conduct Surveillance	Varies 12–15 min	6.0		6.8	4.6		
Move Beyond LD No firing	(G) Conduct Surveillance	Varies 12–15 min	6.0		6.8	4.6		
Move Beyond LD No firing	(L) Conduct Surveillance	Varies 12–15 min	6.0		6.8	4.6		
Identify/Select Target	(TC) Identify Target	00:00:00.37	5.0		6.8			
Identify/Select Target	(TC) Select Target	00:00:00.40			6.8	5.5		
Select Firing Position	(TC) Select Firing Position	00:00:00.07	5.0		6.8			
Move Without Firing During Engagement	(D) Steer Tank	Varies 12–15 min			4.6	2.6		

Table 2. Model task times and workload/data (continued).

Function	Task	Time HH:MM:SS.SS	Visual	Auditory	Cognitive	Fine Motor	Gross Motor	Speech
Move Without Firing During Engagement	(D) Power Tank	00:00:00.40	5.1		1.2	2.2		
Move Without Firing During Engagement	(D) Monitor Instruments	Varies 1–5 s	3.0		6.8			
Move Without Firing During Engagement	(D) Monitor Forward Terrain	Varies 5–15 min	6.0		6.8			
Move Without Firing During Engagement	(TC) Assign Sector Searches	00:00:01.45			7.0			2.0
Move Without Firing During Engagement	(TC) Conduct Surveillance	Varies 12–15 min	6.0		6.8	4.6		
Move Without Firing During Engagement	(G) Conduct Surveillance	Varies 12–15 min	6.0		6.8	4.6		
Move Without Firing During Engagement	(L) Conduct Surveillance	Varies 12–15 min	6.0		6.8	4.6		
Fire While Stationary	(D) Steer Tank (from defilade)	Varies 5–10 min			4.6	2.6		
Fire While Stationary	(D) Power Tank (from defilade)	00:00:00.40	5.1		1.2	2.2		
Fire While Stationary	(D) Monitor Forward Terrain	Varies 5–10 min	6.0		6.8			
Fire While Stationary	(TC) Lay Gun in Direction of target	00:00:03.00	4.4		1.0 / 4.6	2.6		
Fire While Stationary	(TC) Determine Weapon/Announce Alert	00:00:01.45			7.0			2.0
Fire While Stationary	(G) Check/Change Fire Control Select Switch	00:00:00.47	5.0		4.6	2.2		
Fire While Stationary	(L) Check/Change Gun Turret Switch	00:00:00.47	5.0		4.6	2.2		

Table 2. Model task times and workload/data (continued).

Function	Task	Time HH:MM:SS.SS	Visual	Auditory	Cognitive	Fine Motor	Gross Motor	Speech
Fire While Stationary	(G) Check/Change Laser Ranger Finder Switch	00:00:00.47	5.0		4.6	2.2		
Fire While Stationary	(TC) Determine/Announce Ammunition	00:00:01.45			7.0			2.0
Fire While Stationary	(G) Check/Change Gun Select Switch	00:00:00.47	5.0		4.6	2.2		
Fire While Stationary	(L) Check/Change Spent Case Rejection Switch	00:00:00.47	5.0		4.6	2.2		
Fire While Stationary	(TC) Announce Target	00:00:03.45			5.3			2.0
Fire While Stationary	(L) Load Ammo	00:00:03.00	5.0		1.2		3.5	
Fire While Stationary	(G) Check/Change Ammo Select Switch	00:00:00.47	5.0		4.6	2.2		
Fire While Stationary	(L) Check Path of Recoil	00:00:00.37	4.0		7.0			
Fire While Stationary	(TC) Release Override	00:00:00.40			4.6	2.2		
Fire While Stationary	(G) Acquire Target	00:00:00.97	4.0		1.2	4.6		
Fire While Stationary	(TC) Give Fire Command	00:00:00.34			4.6			2.0
Fire While Stationary	(G) Fire Weapon	00:00:00.40			1.0	2.2		
Fire While Stationary	(D) Steer Tank (back to defilade)	Varies 5–10 min			4.6	2.6		
Fire While Stationary	(D) Power Tank (back from defilade)	00:00:00.40	5.1		1.2	2.2		

Table 2. Model task times and workload/data (continued).

Function	Task	Time HH:MM:SS.SS	Visual	Auditory	Cognitive	Fine Motor	Gross Motor	Speech
Fire While Stationary	(G) Observe Fire Effects	Varies 1–5 s	4.4					
Fire While Stationary	(TC) Observe Fire Effects	Varies 1–5 s	4.4					
Fire While Moving	(TC) Lay Gun	00:00:03.00	4.4		1.0 / 4.6	2.6		
Fire While Moving	(D) Steer Tank	Varies 12–15 min			4.6	2.6		
Fire While Moving	(D) Power Tank	00:00:00.40	5.1		1.2	2.2		
Fire While Moving	(D) Monitor Instruments	Varies 1–5 s	3.0		6.8			
Fire While Moving	(D) Monitor Forward Terrain	Varies 12–15 min	6.0		6.8			
Fire While Moving	(TC) Release Override	00:00:00.40			4.6	2.2		
Fire While Moving	(G) Check/Change Fire Control Select Switch	00:00:00.47	5.0		4.6	2.2		
Fire While Moving	(TC) Determine Weapon/Announce Alert	00:00:01.45			7.0			2.0
Fire While Moving	(L) Check/Change Gun Turret Switch	00:00:00.47	5.0		4.6	2.2		
Fire While Moving	(G) Check/Change Laser Ranger Finder Switch	00:00:00.47	5.0		4.6	2.2		
Fire While Moving	(TC) Determine/Announce Ammunition	00:00:00.81			7.0			2.0
Fire While Moving	(G) Check/Change Gun Select Switch	00:00:00.47	5.0		4.6	2.2		

Table 2. Model task times and workload/data (continued).

Function	Task	Time HH:MM:SS.SS	Visual	Auditory	Cognitive	Fine Motor	Gross Motor	Speech
Fire While Moving	(L) Check/Change Spent Case Rejection Switch	00:00:00.47	5.0		4.6	2.2		
Fire While Moving	(L) Load Ammo	00:00:03.00	5.0		1.2		3.5	
Fire While Moving	(TC) Announce Target	00:00:03.45			5.3			2.0
Fire While Moving	(G) Check/Change Ammo Select Switch	00:00:00.47	5.0		4.6	2.2		
Fire While Moving	(L) Check Path of Recoil	00:00:00.37	4.0		7.0			
Fire While Moving	(G) Acquire Target	00:00:00.97	4.0		1.2	4.6		
Fire While Moving	(TC) Give Fire Command	00:00:00.34			4.6			2.0
Fire While Moving	(G) Fire Weapon	00:00:00.40			1.0	2.2		
Fire While Moving	(G) Observe Fire Effects	Varies 1–5 s	4.4					
Fire While Moving	(TC) Observe Fire Effects	Varies 1–5 s	4.4					
Internal Communications (TC)	(TC) Engage PTT Switch	00:00:00.40			1.0	2.2		
Internal Communications	(TC) Communicates	Varies 1–4 s			5.3			4.0
Internal Communications	(G) Listens–Comprehends	Varies 1–4 s		6.0	5.3			
Internal Communications	(L) Listens–Comprehends	Varies 1–4 s		6.0	5.3			
Internal Communications	(D) Listens–Comprehends	Varies 1–4 s		6.0	5.3			

Table 2. Model task times and workload/data (continued).

Function	Task	Time HH:MM:SS.SS	Visual	Auditory	Cognitive	Fine Motor	Gross Motor	Speech
Internal Communications	(G) Acknowledges	00:00:00.34			1.0			2.0
Internal Communications	(L) Acknowledges	00:00:00.34			1.0			2.0
Internal Communications	(D) Acknowledges	00:00:00.34			1.0			2.0
Internal Communications (G)	(G) Engage PTT Switch	00:00:00.40			1.0	2.2		
Internal Communications	(G) Communicates	Varies 1–4 s			5.3			4.0
Internal Communications	(TC) Listens - Comprehends	Varies 1–4 s		6.0	5.3			
Internal Communications 1	(L) Listens - Comprehends1	Varies 1–4 s		6.0	5.3			
Internal Communications	(D) Listens - Comprehends 1	Varies 1–4 s		6.0	5.3			
Internal Communications	(TC1) Engage PTT Switch1	00:00:00.40			1.0	2.2		
Internal Communications	(L) Engage PTT Switch	00:00:00.40			1.0	2.2		
Internal Communications	(D) Engage PTT Switch	00:00:00.40			1.0	2.2		
Internal Communications	(TC) Acknowledges	00:00:00.34			1.0			2.0
Internal Communications	(L) Acknowledges	00:00:00.34			1.0			2.0

Table 2. Model task times and workload/data (continued).

Function	Task	Time HH:MM:SS.SS	Visual	Auditory	Cognitive	Fine Motor	Gross Motor	Speech
Internal Communications	(D) Acknowledges	00:00:00.34			1.0			2.0
Internal Communications	(L) Engage PTT Switch2	00:00:00.40			1.0	2.2		
Internal Communications	(L) Communicates	Varies 1–4 s			5.3			4.0
Internal Communications	(TC) Listens–Comprehends1	Varies 1–4 s		6.0	5.3			
Internal Communications	(D) Listens–Comprehends2	Varies 1–4 s		6.0	5.3			
Internal Communications	(G) Listens–Comprehends2	Varies 1–4 s		6.0	5.3			
Internal Communications	(G) Engage PTT Switch1	00:00:00.40			1.0	2.2		
Internal Communications	(D) Engage PTT Switch1	00:00:00.40			1.0	2.2		
Internal Communications	(TC) Engage PTT Switch3	00:00:00.40			1.0	2.2		
Internal Communications	(D) Acknowledges	00:00:00.34			1.0	2.2		
Internal Communications	(G) Acknowledges	00:00:00.34			1.0	2.2		
Internal Communications	(TC) Acknowledges	00:00:00.34			1.0	2.2		
Internal Communications	(D) Engage PTT Switch2	00:00:00.40			1.0	2.2		
Internal Communications	(D) Communicates	Varies 1–4 s			5.3			4.0

Table 2. Model task times and workload/data (continued).

Function	Task	Time HH:MM:SS.SS	Visual	Auditory	Cognitive	Fine Motor	Gross Motor	Speech
Internal Communications	(TC) Listens - Comprehends2	Varies 1–4 s		6.0	5.3			
Internal Communications	(G) Listens - Comprehends2	Varies 1–4 s		6.0	5.3			
Internal Communications 1	(L) Listens - Comprehends1	Varies 1–4 s		6.0	5.3			
Internal Communications	(TC) Engage PTT Switch2	00:00:00.40			1.0	2.2		
Internal Communications	(G) Engage PTT Switch2	00:00:00.40			1.0	2.2		
Internal Communications	(L) Engage PTT Switch1	00:00:00.40			1.0	2.2		
Internal Communications	(TC) Acknowledges	00:00:00.34			1.0			2.0
Internal Communications	(L) Acknowledges	00:00:00.34			1.0			2.0
Internal Communications	(G) Acknowledges	00:00:00.34			1.0			2.0
External Communications	(TC) Listens–Comprehends	Varies 1–4 s		6.0	5.3			
External Communications	(TC) Engage PTT Switch	00:00:00.40			1.0	2.2		
External Communications	(TC) Acknowledges	00:00:00.34			1.0			2.0
External Communications	(TC) Engage PTT Switch	00:00:00.40			1.0	2.2		
External Communications	(TC) Communicates	Varies 1–4 s			5.3			4.0

3.2.1 Crew

In the IMPRINT model, the Abrams V2 SEP has a crew of four personnel. The four personnel are the tank commander (TC), loader (L), gunner (G), and driver (D). These personnel are the personnel listed in the Tank Platoon Field Manual (2007).

3.2.2 Mission

The scenario modeled by the IMPRINT analysts is a movement to contact mission. The analysts selected this scenario because it is a scenario where the tactical situation is unclear and it requires the crew to seek, identify, and engage potential threats. These activities are common Abrams crew activities (FM 31-20.12, 2005) The crew workload is likely to be high during this scenario for several reasons. First, the tank platoon is trying to gain knowledge about the enemy situation by establishing or regaining contact with the enemy. Secondly, in this offensive scenario the platoon has limited time to plan and prepare (FM 3-20.15, 2007).

In the IMPRINT model that the analysts built to represent this scenario, the crew begins by preparing the Abrams for the mission. They then move from the start point to a checkpoint, a release point, and the beyond the line of departure. After the line of departure, they begin to make enemy contact until the end of the mission.

3.2.3 IMPRINT Crew Functions

Table 3 shows the crew functions in the model and the crewmembers that perform tasks within that function.

Table 3. Crew functions and assignments in the IMPRINT model.

Function	**Crewmember**			
	Tank Commander	**Loader**	**Gunner**	**Driver**
Prepare communications system for operation	X	X	X	X
Refuel tank		—	—	X
Stow ammunition	X	X	X	X
Prepare stations for operation	X	X	X	X
Perform before operations PMCS	X	X	X	X
Perform prefire checks	X	X	X	—
Boresight and zero weapons	X	—	X	—
Drive	—	—	—	X
Conduct surveillance	X	X	X	X
Identify and select target	X	—	—	—
Select firing position	X	—	—	—
Stationary engagement	X	X	X	—
Moving engagement	X	X	X	X
Communicate within Abrams	X	X	X	X
Communicate with platoon leader	X	—	—	—

3.2.4 Model Interfaces

In the IMPRINT model, each of the four Abrams crewmembers performed their assigned tasks using specific equipment or interfaces. Table 4 displays the interfaces each crewmember used to complete a task in the IMPRINT model.

Table 4. Interfaces used by each crewmember in the IMPRINT model.

Crewmember			
Vehicle Commander	**Loader**	**Gunner**	**Driver**
Control handle assembly	Ammunition	Ammo select switch	Brake
CVC helmet	CVC Helmet	CVC Helmet	CVC Helmet
Improved commander's display unit	Direct Vision	Gun select switch	Direct vision
Independent thermal viewer	Gun/turret drive switch	Handles	Integrated display
Intercommunications control set	Intercom control	Improved gun control and display station	Intercom control
Intercom control	Intercommunications control set	Intercom control	Intercommunications control set
Keypad	Loader's Station	Intercommunications control set	Periscope
Machine gun	Main gun breech	Primary sight	Push-to-talk button
Primary sight extension	Periscope	Push-to-talk button	Steer-throttle control
Push-to-talk button	Push-to-talk button	Range switch	Steer-to-indicator
Vehicle	Vehicle	Vehicle	Vehicle

3.2.5 Model Task Times and Workload Data

Table 5 displays the tasks, task times, and mental workload demand values the analyst input into the IMPRINT model. The crewmember the analyst assigned to each task appears in parentheses prior to the task name. TC represents tank commander, G represents gunner, D represents driver, and L represents loader. The analysts combined the tasks into larger groupings called functions. The function names appear in column 1 with the associated task appearing in column 2. The functions represent groups of tasks that have a relationship to each other. For example the function, *crew communications* contains the tasks of the crew listening and talking with each other.

Table 5. Highest workload value for each crewmember.

Crewmember	Highest Overall Workload Values					Concurrent Tasks Performed During High Workload
	Overall	**Visual**	**Auditory**	**Cognitive**	**Motor**	
Tank Commander	39.90	5.0	12.0	17.4	5.5	(TC) Listens–comprehends to crew (TC) Listens–comprehends2 to external (TC) Perform pre-fire checks
Loader	28.70	6.0	6.0	12.1	4.6	(L) Conduct surveillance (L) Listens–comprehends
Gunner	28.70	6.0	6.0	12.1	4.6	(G) Conduct Surveillance (G) Listens–comprehends2
Driver	38.30	14.1	0.0	19.4	4.8	(D) Monitor forward terrain (D) Monitor instruments (D) Power tank (D) Steer tank

4. Discussion of Results

4.1 Driver Workload

As the mission begins, the driver performs a number of pre-combat functions. Specifically he prepares the driver's station and his communications equipment, refuels the tank, stows ammunition, and performs before operations PMCS. During this time, IMPRINT predicted only one instance of high overall workload (overall >28) for the driver. This instance occurs when the driver is listening to a message while performing before operations PMCS check. Similarly, for the individual fine motor mental resource, IMPRINT predicted one instance of high workload during these activities. This instance occurs when the driver is doing a PMCS check that requires discrete adjustment of a knob and he needs to use concurrently the push-to-talk button to respond to a message. It is reasonable to assume that a human operator cannot use both buttons simultaneously which matches the IMPRINT prediction.

Similar to the overall workload predictions, the IMPRINT predictions for the visual, auditory, fine motor, gross motor, and speech individual mental resources did not show any instances of high workload during the pre-mission segment for the driver. However, IMPRINT did predict instances of high workload for the driver's cognitive channel during this time segment. Every time the driver listened to and comprehended a message while performing concurrently another pre-mission task, the cognitive channel was in high workload (channel >7). Because the driver's workload is high, he is likely to manage the workload by changing his performance. In this situation, he can adjust performance by stopping the pre-mission task in order to listen to the message or he may chose to continue the pre-mission task and miss hearing the message.

Once the permission functions are completed, the primary functions the Abrams driver performs are driving and communicating. While performing these two functions, the IMPRINT analysis predicted the driver would frequently experience high workload. This predicted high workload is a combination of driving tasks alone or driving combined with communications tasks.

The driving function in the IMPPINT model consists of several concurrent tasks. The driver monitors the forward terrain, monitors the vehicles instruments, powers up the tank, and steers the tank. As table 5 shows, these four tasks result in an overall workload value of 38.30. This value exceeds the workload threshold value of 28 and indicates the driver is experiencing high workload while driving. The driving function also consistently overloads the cognitive and visual individual channels (>7). Numerous open literature studies (Direct Line Insurance, 2002; Redelmeier, and Tibshirani, 1997; Strayer, Drews, and Johnston, 2003; and Tijerina, 2000) have demonstrated the high workload demands a driver experiences. These studies indicate that driving behavior is an automated behavior that appears to have low workload demands. However, when a driver needs to react to an unexpected event such as another driver running a stop sign or a deer darting across the road, the high workload demands of driving become more apparent. The frequency of automobile accidents in these situations demonstrates the impacts of the high workload demands on driver performance. Because open literature studies predict high workload for car drivers, it is reasonable to assume that the Abrams tank driver would also experience high workload as predicted by the IMPRINT model. Furthermore, tank driving may be more challenging than driving a car. A tank driver, for example, requires assistance when backing up the tank (FM 3-20.12, 2005) whereas a car driver does not. However, similar to the car driver, obstacles may appear before the tank that the driver must avoid. When an obstacle appears, it is likely that similar to a car driver, the tank driver will experience high workload demands. Because the driving tasks themselves contribute to high workload, when the driver performs any other tasks while driver his workload is high. The task he performs most often in addition to driving is communicating with other members of the Abrams crew.

The communications function the driver performs consists of responding or listening to messages from the Abrams commander. This function, when performed independently, does not exceed the threshold of 28 so the driver is not in high workload when communicating with the commander. However, IMPRINT predicts he will experience high workload for communications combined with driving. Table 5 shows that the workload value for the four combined driving tasks exceeds 28. Therefore, adding a communication task to these driving tasks results in predicted high workload that exceeds 28. Out of all the individual channels, the cognitive mental resource channel has the maximum value of 19.4 for the driving tasks. The high workload threshold for a single channel is 7 and is exceeded in this situation. Adding communications task to driving increases the cognitive workload value, which is already over the threshold. The open literature driving studies (Direct Line Insurance, 2002; Redelmeier, and Tibshirani, 1997; Strayer, Drews, & Johnston, 2003; and Tijerina, 2000) have demonstrated that distracter tasks, such as talking on a cell phone, reduce driver performance. A more recent study sponsored by the National Highway Traffic Safety Administration (2006) reported that a driver conducting a cell phone conversation is four times as likely to crash as other drivers. This study concluded that this driver's behavior was equivalent to a blood alcohol content of 0.08. Based on these studies then, it is reasonable to assume that the increased workload predicted by IMPRINT for driving combined with communicating is valid. However, the impacts on performance of communications combined with driving are most likely to occur when the driver is actively engaged in the conversation rather than just listening (Wood, 2005). The Abrams driver, therefore, is most likely to exhibit performance changes when he is actively speaking with another crewmember rather than just listening. While actively engaging in the conversation, the driver may take longer to react to a change in the environment (NHTSA, 2005). These impacts on driver performance predicted by IMPRINT are typical of human mental resource limitations rather than the design of the Abrams tank.

4.2 Gunner Workload

The gunner performs pre-mission functions similar to the driver. He prepares his communications system and workstation for operation, he stows ammunition, performs before operations PMCS and prefire checks, and boresight and zeroes the weapon if necessary. As the Abrams begins to move, the gunner conducts surveillance and communicates. He also engaging targets if necessary. As table 5 shows when he is conducting surveillance and communicating IMPRINT predicted his maximum workload to be 28.70 and this is lower than the driver's maximum workload of 38.30. Although this gunner's task is critical for survivability of the tank crew, the gunner's workload is not high workload.

The majority of the mission time, the gunner's main task is surveillance for targets. For this task, IMPRINT predicted an overall workload value of 17.40 and this is not high workload because it does not exceed the overall workload threshold of 28. However, when the gunner performs communications tasks with surveillance, table 5 shows that the gunner's overall workload value is his highest workload value of 28.70. This workload value is lower than the driver's maximum but it still exceeds the overall workload threshold of 28 and is high workload. As table 5 shows, IMPRINT predicted this maximum value occurs when the gunner is trying to comprehend a message while doing other tasks such as surveillance. The cognitive channel is the mental resource channel that contributes most to this high overall value. As table 5 shows, this channel has a maximum value of 12.1 and this value exceeds the single channel workload threshold of 7. To manage the effects of this high workload on his performance, a strategy the gunner might employ would be to perform the tasks sequentially (Hart, 1991). If this occurs then he will either process the message then search for targets or search for targets then process the communications. Either of these options is likely to decrease his performance.

4.3 Loader Workload

While the tank is moving and the crew is searching for potential threats, the loader performs the same functions as the gunner. However, during target engagements, while the gunner is locating and engaging targets, the loader is loading the ammunition. Because they are performing similar functions during much of the mission, as table 5 shows, the maximum workload value for the loader is the same as the maximum workload for the gunner. Similar to the IMPRINT predictions for the gunner, IMPRINT predicted the loader's high workload to result from the overload on the cognitive channel from the combination of listening to and comprehending a message while performing other tasks. Table 5 shows the maximum value for the cognitive channel was 12.5 as it was for the gunner. Because both positions experience high workload while comprehending messages, it is possible that the gunner or loader could share monitoring of the same communications. This redundancy would help mitigate the impacts of high workload on communications performance for the two positions.

4.4 Tank Commander Workload

The tank commander performs the functions of the other Abrams crewmembers and also communicates and coordinates with the platoon leader. As table 5 shows, when the tank commander is completing prefire checks while trying to coordinate communications within the Abrams as well as with the platoon leader, his workload reaches a maximum value of 39.90. This value exceeds the threshold of 28 and is high workload. During this high workload, table 5 shows his auditory channel to have a maximum value of 12.0 and his cognitive channel has a value of 17.4. Because each of these channels exceeds the single channel workload threshold of 7, they are both overloaded. It is reasonable to assume that an individual would have difficulty listening to two concurrent messages from two different sources as predicted by IMPRINT. To manage this high workload, the commander may employ the workload management strategy of performing the tasks sequentially (Hart, 1991). To do this he would attend to each message sequentially. Performing the communication tasks sequentially would result in a delay in responding to either the platoon leader's or his crew's messages.

Trying to comprehend a message during PMCS tasks, Prefire checks, and surveillance all result in high workload.

In addition to communications tasks contributing to high workload during pre-fire checks, it contributes to the tank commander's high workload during the combat mission. Similar to the gunner and the loader, the tank commander scans for threats as the tank moves across the battlefield and communicates with the crew. In addition, the tank commander communicates with the platoon leader. IMPRINT predicted the tank commander's combination of scanning and communications to have a value of 28.70. This is the value displayed for the gunner and loader in table 5 for these tasks. The tank commander's primary responsibility is the tank crew. The gunner's primary responsibility, on the other hand, is target detection. Therefore, to manage his high workload, the tank commander is likely to focus on communicating with the crew and platoon leader and rely on the gunner to detect targets.

5. Conclusions and Recommendations

The tank commander and driveer have the highest workload among the four crewmembers. The tank commander's workload is highest because he performs the function of the other crewmembers while also communicating and coordinating with the crew and platoon leader. The driver's high workload is a result of the four concurrent driving tasks of monitoring the forward terrain, powering the tank, steering the tank and monitoring the instruments. Because his workload is high for driving, actively engaging in conversations is likely to increase his workload and result in some driving performance degradation. The tank commander, gunner and loader have lower maximum workload then the driver. All three of these positions scan for targets and communicate. When they are performing these tasks concurrently, they are likely to experience high workload. However, because all three crewmembers are performing these tasks, they can manage the workload by assigning surveillance primarily to the gunner and communications to the tank commander. The loader can be a back-up for either of these two positions performing theses tasks when necessary.

The workload levels IMPRINT predicted for each of the crewmembers can be used as thresholds to evaluate the impacts of proposed technologies on crew workload and performance. The new technology should maintain workload at or below the level of the baseline model while maintaining or improving crew performance.

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List of Symbols, Abbreviations, and Acronyms

ARL	U.S. Army Research Laboratory
D	driver
FCS	Future Combat System
G	gunner
GUI	graphic user interface
I–EBCT	Early–Infantry Brigade Combat Team
IMPRINT	Improved Performance Research Integration Tool
L	loader
M1A1	Abrams tank
MRT	Multiple Resource Theory
SEP	system enhancement package
TC	tank commander

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